Project Title: Causes, Consequences, and Management of Nuisance *Cladophora*

Name and Address of Organization:
University of Wisconsin-Milwaukee
Great Lakes WATER Institute
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Milwaukee, WI, 53204

Benefit to Organization: The primary mandate of the UWM Great Lakes WATER Institute is to conduct research on Lake Michigan and the other Laurentian Great Lakes that improves our understanding of the biological, chemical and physical properties and processes in these lakes, and provides information and knowledge necessary for the sustainable management of these large aquatic ecosystems. The proposed project will directly addresses these objectives, and will enable the Great Lakes WATER Institute to achieve these goals by providing support for research staff, research operational costs, and research equipment.

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Programmatic Capability:

Our laboratory began addressing the *Cladophora* issue in Lake Michigan two years ago. The lab of H. Bootsma is addressing a number of issues on Lake Michigan, but the primary focus is *Cladophora* and nearshore nutrient / carbon cycles. Therefore, current lab and field programs are optimized to examine this issue.

Although we have not previously conducted projects with EPA-GLNPO support, we have conducted several projects similar in size to that being proposed here. These include a Wisconsin Sea Grant funded project to examine the influence of trophic structure and carbon source on PCB transfer in the Lake Michigan food web, a NOAA-funded project to develop real-time, in situ water quality monitoring systems (http://waterbase.glwi.uwm.edu), and a project funded by the Wisconsin Coastal Management Program to determine the spatial distribution of Cladophora in Lake Michigan (http://www.uwm.edu/Dept/GLWI/cladophora/page_coastalimagery.html). Each of these projects had stringent requirements for mid-term and final reports, all of which were met. H. Bootsma has also previously directed a large, international, multi-disciplinary research / management program on Lake Malawi (East Africa). This project required a high degree of organization, as well as regular reporting to a number of funding institutions. It was rated by the Global Environmental Facility as one of the most successful projects that they have supported with regard to research excellence and

management applications. The results of this project have been made available on the internet (http://www.uwm.edu/People//hbootsma/Lake%20Malawi/LkMal.html) and in a special issue of the Journal of Great Lakes Research, for which H. Bootsma served as the lead editor.

The UWM Great Lakes WATER Institute is a leading research laboratory on the Laurentian Great Lakes, with a fully equipped research vessel (RV Neeskay), several smaller research boats, and a wide array of sampling equipment. Researchers are trained in SCUBA sampling surveying. Research labs are equipped with state-of-the-art equipment for analyses of nutrients, algal pigments, dissolved gases, and stable isotopes. The laboratory has a rigorous QA/QC protocol which includes analysis of "blind" samples within environmental sample sets, the application of check samples to assure long-term reliability of data, and a post-analysis data filtering / flagging protocol.

Project Description:

The filamentous alga, *Cladophora* sp., has recently increased in abundance on the western shores of Lake Michigan to the point where it has again become a nuisance to beach goers and lakeshore dwellers, a hazard at water intakes, and a potential health threat. Our work will address the hypothesis that the resurgence of *Cladophora* is the result of the alteration of nearshore nutrient cycles by zebra and quagga mussels. This will be done by combining nearshore ecosystem monitoring with *in situ* experiments. In addition, we will examine the ecological consequences of excessive *Cladophora* production on the nearshore food web, and develop a computer model that will allow managers to test the efficacy of various management options.

Key Terms: algae, benthos, dreissenids, beach fouling, nutrients, phosphorus, carbon, food web.

Problem Statement:

In Lake Michigan and the other Great Lakes there has been a recent resurgence of nuisance blooms of benthic algae, dominated by the invasive, green, filamentous alga, *Cladophora* sp. (Edsall and Charlton 1996; New York Sea Grant 2002; Milwaukee Journal Sentinel 2002). Negative impacts of these algal blooms include unsightly and foul smelling beaches, potential health risks from bacterial growth, clogging of water intakes and impaired quality drinking water, decline in lakeshore recreational quality and property depreciation. In addition, excessive *Cladophora* growth reduces fish and invertebrate species diversity, and may negatively affect spawning success of some fish species (Oster 1980), either by modifying the substratum or by promoting anoxia during decomposition (Hartman 1973).

Our recent research has shown that *Cladophora* growth in nearshore Lake Michigan is P-limited in high light areas, but is probably light-limited at depths greater than 10 m and is

seasonally limited by temperature (Bootsma et al. 2004). In Lake Michigan and the other Great Lakes, external P loading has apparently decreased by 50% or more over the past two to three decades (Nicholls and Hopkins 1993; DePinto and Narayanan 1997; Barbiero et al. 2002), yet *Cladophora* growth and shoreline deposition has escalated over the last decade. This suggests that either, 1) nearshore nutrient cycles have been altered so that the lake's internal nutrient pool has become more available to benthic algae, or 2) phosphorus inputs may actually be increasing, if not at the whole-lake scale then at least at a local scale. A third possibility is that both of the above are occurring. Determining which of these factors is responsible for the *Cladophora* resurgence is critical from a management perspective, as management options will differ greatly for these two scenarios.

Support for the hypothesis that internal nutrient cycles have been altered comes from our recent research, which suggests that in the Milwaukee region, only a small proportion of the P required to support *Cladophora* growth comes from new P inputs via major riverine sources and much of the *Cladophora* growth must be supported by P cycling within the lake (Bootsma et al. 2004). This hypothesis is supported by the observation that, whereas *Cladophora* was previously a localized problem related to riverine nutrient inputs (e.g. Canale and Auer 1982; Lekan and Coney 1982), it now appears to be a much more widespread problem affecting large stretches of coastline. For example, an aerial survey conducted in the summer of 2004 revealed that *Cladophora* is abundant over most of the Wisconsin coast of Lake Michigan, even in areas remote from inflowing rivers. We hypothesize that this change has occurred as a result of the establishment of dreissend mussels - the zebra mussel, *Dreissena polymorpha*, and the more recently introduced quagga mussel, *Dreissena bugensis*.

Zebra mussels are extremely efficient at filtering water, resulting in the removal of phytoplankton and suspended sediment from the water column (Fahnenstiel et al. 1995; Caraco et al. 1997) and deposition of nutrients in the benthos, which can accelerate nitrogen and phosphorus recycling (Gardner et al. 1995; Heath et al. 1995), and may make nutrients more available for uptake by the benthic community, particularly *Cladophora*. Recent experiments indicate that *Cladophora* growth is accelerated in the presence of zebra mussels (Stankovich 2004).

We propose to conduct a series of experiments and field surveys to test the hypothesis that dreissenid mussels are promoting *Cladophora* growth. The results of this work will be used to revise a *Cladophora* growth model. This model will then be a tool that will allow managers to assess the efficacy of various management options in reducing *Cladophora* abundance. In particular, the proposed research will allow managers to determine whether further phosphorus abatement, such as limiting phosphorus in fertilizers, as is being done in some parts of Wisconsin and Minnesota, is a feasible means of controlling *Cladophora* production in Lake Michigan and other Great Lakes.

While the direct impacts of *Cladophora* on human activities are relatively obvious, very little is known of the potential ecological effects of excessive *Cladophora* growth in the Great Lakes. The algae, in combination with high densities of dreissenid mussels,

appears to effectively retain nutrients within the nearshore zone (Hecky et al. 2004). This nutrient retention results in high algal productivity in the nearshore zone, but a decline in the numbers of benthic amphipds (*Diporeia*, Nalepa et al. 2006) in deeper waters suggests that this nearshore increase in production may be at the expense of pelagic production. A critical question is whether the nearshore benthic algal production represents a dead end in the lake's food web, or if this production makes a significant contribution to the energy requirements of higher trophic levels. We plan to address this question by quantifying nearshore primary production rates, and by using stable isotopes to determine the relative importance of *Cladophora* to critical fish and invertebrate species in the Lake Michigan food web.

Proposed Work:

Our proposed work program will use a combination of lab experiments, field experiments and field surveys to address three questions:

1. What role do dreissenid mussels play as a nutrient source for *Cladophora*?
2. Do river inputs of phosphorus have a direct influence on *Cladophora* production?
3. What is the magnitude of carbon flux to the nearshore zone as a result of *Cladophora* production, and what is the significance of this carbon flux to the Lake Michigan food web?

The results of this work will then be used to update a *Cladophora* model, which will be made available to managers and policy makers.

The project will achieve these objectives through 7 primary tasks:

1. Measuring and modeling P recycling by mussels.
2. Validating key processes in an existing *Cladophora* model.
3. Developing a *Cladophora* model framework with a graphical user interface.
4. Assess the influence of river P input on *Cladophora* growth.
5. Update the *Cladophora* model to include P flux from dreissenid mussels.
6. Quantify community-scale primary production by *Cladophora*.
7. Conduct a workshop to introduce the *Cladophora* model and provide training in its use.

Throughout the implementation of this project, we will continue our collaboration with the Wisconsin Department of Natural Resources, to ensure that our research activities are complementary, and that all research results are used for both education and management purposes.

1. The dreissenid – *Cladophora* relationship. Measuring and modeling P recycling by mussels.

Our ultimate goal of developing a reliable *Cladophora* growth model requires an understanding of the mechanisms controlling phosphorus supply to *Cladophora*. While our previous research provides strong evidence that dreissenids are an important source of P, we need to quantify this source in the lake, and determine how it is influenced by the main controlling factors of temperature, food supply and mussel density.

We will conduct a series of 2X2 factorial experiments in which the P recycling rate of mussels is measured in response to a range of food supply rates, temperatures. Mussels will be fed phytoplankton concentrations similar to those observed for Lake Michigan. Following 3 weeks of acclimation to a given phytoplankton concentration, subsamples will be collected from incubation chambers at time intervals ranging from hourly to daily over a 5-day period and analyzed for soluble reactive phosphorus (SRP) and total dissolved phosphorus (TDP) using a longpass flow cell spectrometer to maximize sensitivity. These experiments will be repeated at three different temperatures (12, 17 and 22°C). In all incubations, moderate levels of turbulence will be maintained by bubbling with air stones.

The results of the above experiments, along with published data on mussel P regeneration, will be used to develop algorithms describing phosphorus recycling by mussels as a function of temperature, and plankton abundance. These algorithms will then be used to develop a mussel P recycling sub-model to be included as part of the *Cladophora* growth model.

2. Validation of existing *Cladophora* model. The model we propose to develop will be a modification of a model developed previously by M. Auer and colleagues. The core process that the model simulates is *Cladophora* growth as a function of irradiance, temperature and tissue P content. Prior to including a mussel P recycling component in the model, it is critical that the algorithms describing this core process are verified. This will be done by collecting *Cladophora* from the lake and measuring photosynthetic rates in the laboratory under a gradient of temperature and light conditions, using a *Cladophora* photosynthesis incubator we have built. P content of the *Cladophora* will be measured immediately following photosynthesis incubations. Measured photosynthetic rates will be compared with rates that are predicted by the model for given temperature, irradiance and P content levels.

A second critical property of the existing model is the relationship between *Cladophora* tissue P content and ambient SRP concentration. This relationship is dependent on *Cladophora* photosynthetic rate. By measuring photosynthetic rate along with *Cladophora* P content and ambient SRP concentrations, we will be able to validate this component of the *Cladophora* model. Samples for ambient SRP analysis will be collected in acid-washed bottles and analyzed using the longpass flow cell spectrometer.

3. Development of a *Cladophora* model framework. The *Cladophora* growth model will be built on a previous model developed by M. Auer and colleagues (documented in a 1982 special issue of the Journal of Great Lakes Research, Vol. 8, No. 1). Although the

earlier model needs to be modified to be applicable under current conditions in Lake Michigan (the model was developed prior to the dreissenid invasion), its core structure remains valid and therefore it is an ideal starting point for an updated model. In year 1, we will validate the core processes simulated by the model, re-parameterize these processes if the new data warrant it, and develop a graphical user interface that will make the model easier to use (operation of the previous model requires training in computer programming). This work will be carried out in collaboration with Dr. M. Auer at Michigan Technological University. Dr. Auer has considerable experience in experimental studies and mathematical modeling of *Cladophora*, having served as the principal investigator for two large *Cladophora* research projects in the early 1980s, when there was a *Cladophora* problem in the Great Lakes similar in magnitude to that observed today. Beta versions of the model and graphical user interface will be tested by WDNR staff, and revisions will be made based on their feedback.

4. Assessing the impact of river phosphorus inputs. To assess the role of rivers as a potential nutrient source promoting *Cladophora* growth, sampling transects will be established near the mouths of two rivers – the Milwaukee River, which is a large P source, and the Pigeon River, which is a moderate P source. Both sites will be sampled on two occasions, once during a dry, low-discharge period, and once within 1 week after a major rain event. On each occasion, *Cladophora* samples will be collected in triplicate along a long-shore transect at a depth of 8 m at 500 m intervals, spanning a distance from 3 km south to 3 km north of the river mouth. Samples will be collected from a prescribed rock surface area (20 X 20 cm), which will allow for measurement of biomass density. Samples will be analyzed for tissue P content and stable isotope ($\delta^{15}N$ and $\delta^{13}C$) ratios. If rivers have a significant influence on *Cladophora* growth, then we expect that P content will decrease with distance from river mouth, as will $\delta^{13}C$ (which is a useful surrogate for algal relative growth rate). This task will be coordinated with the sampling activities of the Wisconsin DNR, which plans to conduct large-scale coastal surveys of nutrients and *Cladophora* in the summer of 2006. This will allow us to place the results of our river mouth transect measurements into the larger context of *Cladophora* nutrient status along much of the western coast of Lake Michigan.

   In addition to sampling near the two river mouths, we will collect samples from a remote site with no river influence – North Manitou Island in Sleeping Bear Dunes National Lakeshore. We have recently been contacted by the National Park Service and asked to assist them in assessing the magnitude and potential causes of the *Cladophora* problem at this location. We will conduct an initial sampling survey in the summer of 2006, which will include measurements of *Cladophora* biomass, tissue phosphorus content, photosynthetic rate and water column particulate and dissolved phosphorus concentrations at sites around the island that the Park Service has identified as having excessive *Cladophora* growth. These data will provide a useful endpoint for our assessment of the potential influence of river nutrient inputs on *Cladophora* growth. During our initial visit, we will work with Park research staff to set up a sampling program to collect *Cladophora* and nearshore water samples through the remainder of the growth season (until late September). These samples will be sent to the Great Lakes Water Institute for analyses. The resulting data will be compared with data from the river

mouth sites for the purpose of our research program, but all data will also be provided to the National Park Service.

5. Update the *Cladophora* model to include P flux from dreissenid mussels. The research conducted in year 1 will allow us to develop a dreissenid mussel nutrient cycling model, simulating mussel P supply as a function of temperature and food supply. By adding this sub-model to the existing *Cladophora* model framework, the model will be applicable to current conditions in Lake Michigan (and possibly the other Great Lakes), and will once again be useful as a management and educational tool. In addition to adding a dreissenid mussel component, lab and field experimental results from year 1 will be used to determine if any of the key processes simulated by the model need to be re-parameterized, and suggestions received from test users in year 1 will be used to determine if any changes are required in the design of the graphical user interface and output formats.

To validate the mussel P cycling sub-model, field experiments will be conducted to quantify *in situ* P recycling rates. This will be done through a combination of *in situ* chamber incubations and direct measurements of vertical P flux from mussel beds. For chamber experiments, mussels will be placed in chambers at densities similar to those on the lake bottom, and chambers will be sub-sampled at 1-hour intervals to determine changes in SRP and TDP concentrations. In addition, near-bottom micro-profiles of SRP, TDP, temperature and currents will be measured. Current micro-structure will be used to determine near-bottom turbulence and vertical mixing which, when combined with SRP and TDP profiles, will allow use to estimate vertical P flux from mussel beds. Micro-profiles of SRP and TDP will be sampled using a small-volume micro-sampler that we have recently built at the Great Lakes WATER Institute. This combined with the small volume requirements of the longpass flow cell spectrometer, allows for the measurements of vertical P profiles with a spatial resolution of several mm.

Further attempts to refine the model will be made by examining the factors that affect *Cladophora* sloughing within the lake. Previous attempts to model the sloughing process have had limited success, but the earlier work of Auer and colleagues indicated that a better understanding of this process would improve the model's performance. We will examine the relationship between sloughing and environmental conditions by monitoring *Cladophora* on a daily basis using an underwater camera attached to a monitoring buoy. This buoy (with instruments to monitor water quality and currents) and camera will be set up with funding from alternate sources. By collecting daily data on sloughing, water temperature, dissolved oxygen, current speed / direction, light, and meteorological conditions, we will be able to determine whether standing stock alone is the primary factor causing sloughing (as previous models have assumed), or if other factors such as temperature, light and turbulence also play a role.

6. Quantify community-scale primary production by *Cladophora*. The large amounts of *Cladophora* that grow in the nearshore zone represent a source of organic carbon that is significant within the shallow waters of the lake, and may even be significant on a whole-lake scale. Hence the fate of this organic carbon may have important ramifications for

the lake's food web. We will use a CO_2/O_2 monitoring system that we have recently developed to continuously monitor air-water flux of CO_2 and O_2 in the nearshore zone. We have built one system, and we propose to build two more to monitor a nearshore-offshore transect near our standard station north of Milwaukee. The system is deployed on a surface buoy, and continuously monitors near-surface water and air gas concentrations with a high resolution (≤ 1 ppm for CO_2). When combined with water temperature data and meteorological data (especially wind speed), the gas concentrations are used in a boundary layer model (e.g. Jahne et al. 1987; MacIntyre et al. 1995) to determine the net air-water gas flux. Continuous monitoring will allow us to determine the long-term net flux of carbon and oxygen in this zone, and the potential significance of nearshore benthic algal production as an energy source to organisms in the lake.

We will install two continuous CO_2/O_2 monitoring systems on buoys immediately south and north of Milwaukee, at locations where the bottom depth is between 8 and 10 m. These locations are chosen because they will allow us to determine the potential effect of river nutrient inputs on *Cladophora* production and lake-atmosphere gas exchange. At the southern location, known as the "Green Can" station (because of the presence of a large, green navigational buoy), a number of other measurements will be made as part of the Great Lakes WATER Institute's Great Lakes Urban Coastal Observation System, which will include continuous temperature profiles, current profiles, turbidity, phytoplankton chlorophyll *a,* and surface meteorological conditions. These additional measurements will allow us to parameterize the air-water gas exchange model, and provide physical and chemical data that will allow us to interpret the causes of fluctuations in *Cladophora* productivity as inferred from air-water gas exchange measurements.

We have recently collected preliminary data on the stable isotope composition of *Cladophora* and some nearshore organisms. These data indicate that the ^{13}C enrichment of *Cladophora* (generally reported as $\delta^{13}C$) is different enough from that of phytoplankton that it can be used as a trophic tracer (the $\delta^{13}C$ of a consumer is nearly identical to that of its food source). The data also indicate that at least some nearshore organisms, including small lake trout, appear to rely on a food web that is ultimately supported to a large degree by *Cladophora* production. We plan to augment these data with further analyses to provide a more complete picture of nearshore food web structure and the relative importance of *Cladophora* as an energy base for this food web. When compared with other current studies of population dynamics and feeding behavior of pelagic organisms in Lake Michigan, these data will also provide a more complete understanding of trophic structure in Lake Michigan.

7. Conduct a workshop to introduce the *Cladophora* model and provide training in its use. Following completion of the revised model, we will organize a one-day model training workshop, to be held at the UWM Great Lakes WATER Institute in Milwaukee. Attendees will receive the model training manual, and will be provided instruction in the operation of the model software. Workshop invitations will be extended to the Wisconsin DNR, National Park Service, Wisconsin Coastal Management Program (WCMP), and other smaller scale management agencies in Wisconsin, including the Milwaukee

Metropolitan Sewerage District (MMSD), the Manitowoc County Soil and Water Conservation Department, and the Health Departments of cities on the Wisconsin coast of Lake Michigan. Workshop materials will include the logos of EPA, MMSD and WCMP.

Environmental Results:

Cladophora currently has a number of negative impacts on communities around the Great Lakes. The most obvious impact is the decline in aesthetic quality of beaches resulting from the sight and smell of large amounts of rotting *Cladophora.* In addition, there is evidence that *Cladophora* may sustain or promote the growth of bacteria, including coliforms. While it is uncertain whether this presents a direct health risk, it may certainly confound the use of coliform bacteria as an index of health risk in nearshore waters. More direct economic impacts results from property depreciation (in the Milwaukee region complaints from lakeshore land owners have prompted State Representatives to consult us on the causes of, and potential solutions to, the *Cladophora* problem) and financial burdens for industries that have water intakes in the lake (in January 2004, the Kewaunee Nuclear Power Plant was forced to shut down because *Cladophora* had clogged its emergency cooling pumps (see http://www.jsonline.com/bym/news/jan04/201605.asp).

Within Wisconsin, excessive growth of *Cladophora* in Lake Michigan is recognized by the Department of Natural Resources to be a serious problem (see http://dnr.wi.gov/org/caer/ce/news/on/2005/on050125.htm#art2). *Cladophora* is also seen as a priority problem in Lakewide Management Plans for Lake Erie, and in the most recent LaMP Report for Lake Michigan, *Cladophora* was identified as one of eight near-term research objectives (http://www.epa.gov/glnpo/lakemich/2004update/lmlamp04_2b.pdf). Among the EPA's list of Delisting Targets for Areas of Concern in the Great Lakes, four issues are potentially influenced by *Cladophora* growth: 1) beach closings; 2) eutrophication / undesirable algae; 3) dissolved oxygen depletion of bottom waters; and 4) degradation of aesthetics.

Currently, policy makers within Wisconsin are considering the possibility of limiting the use of phosphorus-containing fertilizers. This consideration has largely arisen as a result of the *Cladophora* problem on the western shores of Lake Michigan. However, before making a decision that would have a potentially huge economic impact on industry and agriculture, solid scientific data is needed to determine whether such an action would have the desired effect. Such data are currently not available. The work we propose here will provide insight into the mechanisms that are promoting excessive *Cladophora* growth in Lake Michigan and other Great Lakes. This insight is a critical prerequisite to determining what, if any, management strategies may be effective in reducing *Cladophora* growth and improving nearshore water quality.

The specific work outcomes and products that we will produce to address the above needs will include:
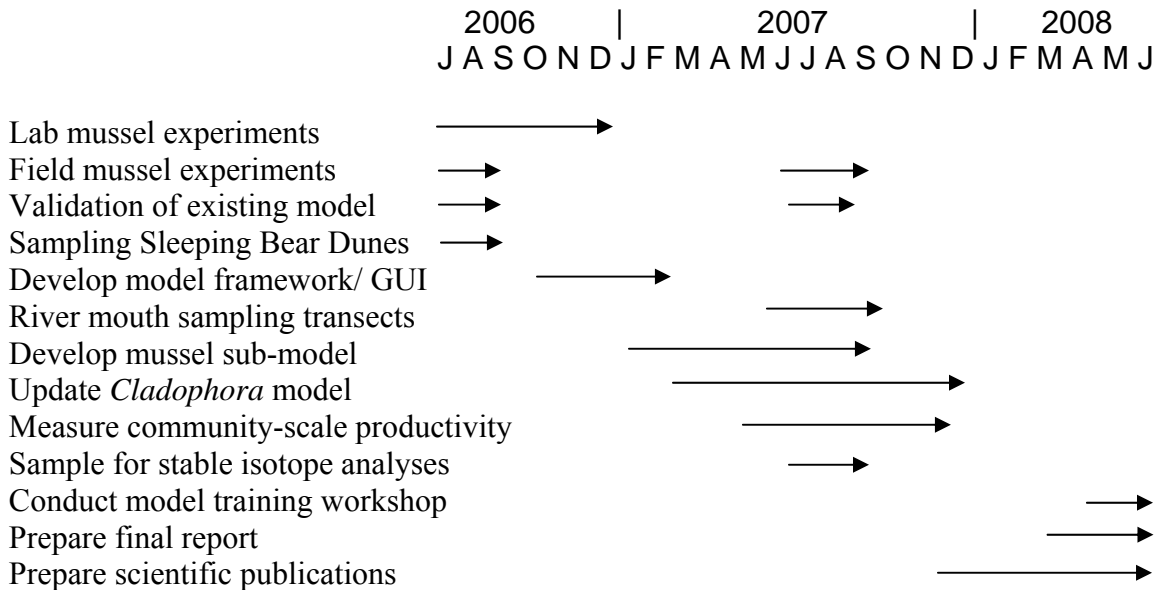
Products

1. A dynamic *Cladophora* model that simulates *Cladophora* growth and biomass, using input of solar radiation, water clarity, temperature, and phosphorus input. The model will include a sub-component to simulate the contribution of dreissenid mussels to P input, with an input of temperature, mussel density and suspended seston concentration.
2. A graphical user interface that facilitates application of the *Cladophora* model.
3. A manual documenting the details of the *Cladophora* model and providing user instructions.
4. A final project report that will include:
    o Model simulation outputs under specific management scenarios
    o Recommendations regarding the potential to reduce *Cladophora* abundance by reducing river P loads.
5. A public information website with a description of the research program and discussion of the research results.
6. A training workshop at which staff of various management organizations (Wisconsin DNR, Wisconsin Coastal Management Program, Milwaukee Metropolitan Sewerage District, EPA, National Park Service) are provided with training in the use of the *Cladophora* model.
7. Publications in the scientific literature. We foresee a minimum of three publications focusing on the *Cladophora* model, nearshore phosphorus dynamics, and the role of *Cladophora* in the nearshore food web and carbon dynamics.

Outcomes

1. An assessment of the relative roles of dreissenid mussels and river inputs as sources of phosphorus to *Cladophora*.
2. Users (primarily management staff) trained in the operation of the *Cladophora* model
3. A public that is more informed of the causes and possible management solutions to the *Cladophora* problem in the Great Lakes.
4. This project will not implement or test any specific strategies that will address the *Cladophora* problem. It will provide the information required to inform such strategies. Depending on the degree to which these strategies are implemented, a potential long-term outcome of this project is improved water quality and beach quality in the nearshore zone of Lake Michigan and other Great Lakes.

Measurement of Progress:

Pending the availability of funds, it is anticipated that this project will commence in July 2006. Progress will be monitored by comparison of project performance with the below schedule and milestones:

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                          2006        |      2007        |    2008
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Lab mussel experiments

Field mussel experiments

Validation of existing model

Sampling Sleeping Bear Dunes

Develop model framework/ GUI

River mouth sampling transects

Develop mussel sub-model

Update *Cladophora* model

Measure community-scale productivity

Sample for stable isotope analyses

Conduct model training workshop

Prepare final report

Prepare scientific publications

Milestones:

Completion of initial model framework and GUI	December 2006
Completion of lab mussel experiments	December 2006
Validation of existing model	September 2007
Completion of field mussel experiments	September 2007
Completion of mussel sub-model	December 2007
Installation of CO_2 monitoring buoy	May 2007
Completion of model beta version	October 2007
First scientific publication	December 2007
Complete review of model beta version	December 2008
Completion of revised model and GUI	February 2008
Completion of model manual	March 2008
Model workshop	April 2008
Submission of final report	June 2008

Quality Assurance Plan

A Quality Assurance Project Plan (QAPP) document has been separately prepared for this project.

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